

Electromagnetic form factors of the nucleon in a relativistic quark pair creation model

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Abstract

We study the effects of the $|qqq\ q\bar{q}\rangle$ component of the hadronic wave function on the description of the electromagnetic structure of the nucleon. Starting with a $3q$ baryonic wave function which describes the baryonic and mesonic low energy spectrum, the extra $q\bar{q}$ pair is generated through a relativistic version of the 3P_0 model. It is shown that this model leads to a renormalization of the quark mass that allows one to construct a conserved electromagnetic current. We conclude that these dynamical relativistic corrections play an important role in reproducing the Q^2 dependence of the electromagnetic form factors at low Q^2 .

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1 Introduction

Electromagnetic processes constitute a basic tool to investigate the baryon structure since the photon couples to the spin and flavor of the constituent quarks, revealing their spin-flavor correlations inside the baryons. This explains the current experimental effort along this line (MAMI, ELSA, GRAAL) with specific experimental programs in TJNAF [1].

From a theoretical point of view, most analyses rely on the use of the non-relativistic quark model [2] in spite of the fact that for the low-lying non-strange resonances the velocity of the quarks inside the baryons may be close to c . Incorporation of two-body exchange currents does not mean much improvement on the results [3]. On the other hand, attempts to use relativized quark models combined with consistent transition operators have been carried out [4, 5] and Light-Front and Point-Form studies have also been done [6, 7] partially solving some of the failures of the non-relativistic approach. However, a complete understanding of the relevant ingredients in the description of electromagnetic processes has not been reached yet.

Our aim in this article is to investigate the role played by some relativistic corrections to the electromagnetic transition operators, specifically those ones related to the coupling of the photon to $q\bar{q}$ components of the baryon (mesonic cloud), also underlying the well known Vector-Meson Dominance phenomenology. The need for the *explicit* contribution of the cloud to describe electromagnetic interactions of baryons was also concluded in [8], where it was shown on very general grounds that meson exchange in the qq potential can not play the role of the $|qqq\ q\bar{q}\rangle$ configurations in the baryon. The importance of the explicit consideration of the meson cloud for electromagnetic processes has been recently studied in Ref. [5].

A main motivation for this study comes from the analysis of strong pionic decay processes where the implementation of the coupling of the pion to $q\bar{q}$ baryon components through a 3P_0 operator allows a reasonable description of the decay widths [9]. In comparison to the elementary emission model, the improvement is especially spectacular for the Roper resonance since the decay width for the $N\pi$ channel has changed from a few MeV to few hundreds MeV. However, as shown in [10], the precise value is open to discussion.

By proceeding in the same way for the electromagnetic transition operator a first simplified model for the photo and electroproduction amplitudes of $N(1440)$ was presented in [11]. These results suggest that the explicit contribution of the baryon mesonic cloud (taken implicitly into account in the baryon spectrum through the effective parameters and/or interactions of the potential) is an essential ingredient for the description of transition processes from a non-relativistic quark model scheme.

Here we apply the same ideas to construct a more complete and consistent

model to deal with electromagnetic processes that we shall test by evaluating the nucleon form factors. We put the emphasis in the construction of an effective transition operator to be sandwiched between effective quark–core wave functions as the ones provided by spectroscopic models. In particular we shall center in a model previously used to fit the baryon and meson spectrum [12] and to predict strong pionic decay widths [9], though our treatment can be applied to *any other* quark–core model of the baryon structure.

The paper is organized as follows. In section 2 we discuss the direct quark–photon coupling through the elementary emission model that we shall apply to the calculation of nucleon form factors. In section 3 we study dynamical relativistic corrections induced by $q\bar{q}$ pairs in the baryonic medium. A 3P_0 model will be used in order to implement the relevant $qqq\ q\bar{q}$ baryon components. From the consideration of resonant and non-resonant diagrams we are driven in section 4 to develop a gauge invariant model. Results are presented and discussed in section 5.

2 The elementary emission model (EEM)

In the EEM the baryon transition process $B \rightarrow B'\gamma$ is described by assuming that the photon is emitted by a constituent quark of the baryon (Fig. 1a). The relevant matrix element between quark states is written as:

$$\langle q(\vec{p}')\gamma(\vec{q}, \lambda) | H_{qq\gamma} | q(\vec{p}) \rangle = \frac{e_q}{(2\pi)^{3/2}} \frac{1}{(2\omega_\gamma)^{1/2}} \delta^{(3)}(\vec{p} - \vec{p}' - \vec{q}) O_{qq\gamma}^{\text{EEM}}(\vec{p}, \vec{p}', \lambda) , \quad (1)$$

where e_q is the quark charge, λ is the state of polarization of the photon, ω (\vec{q}) its energy (three-momentum) and \vec{p} (\vec{p}') is the three-momentum of the initial (final) quark. By considering the usual electromagnetic current for point–like fermions the single–quark transition operator $O_{qq\gamma}^{\text{EEM}}$ reads:

$$O_{qq\gamma}^{\text{EEM}}(\vec{p}, \vec{p}', \lambda) = \left(\frac{m}{E_p} \right)^{1/2} \left(\frac{m}{E_{p'}} \right)^{1/2} \bar{u}(\vec{p}') \gamma_\mu u(\vec{p}) \epsilon_\lambda^\mu(\vec{q}) , \quad (2)$$

where $\epsilon_\lambda^\mu(\vec{q})$ is the photon polarization four–vector, E_p ($E_{p'}$) the on-shell energy of the initial and final quarks ($E_p = \sqrt{m^2 + \vec{p}^2}$), and m the mass of the quarks which is assumed to be the same for all of them.

From (2) the conventional way to derive a non-relativistic transition operator is to proceed to a (p/m) expansion keeping terms up to the first order [2]. Nevertheless for light baryons in a quark model this procedure is under suspicion since the quarks move inside the core with relativistic velocities and then $\langle p/m \rangle$ can be even bigger than 1. On the other hand a more reasonable expansion in terms of the relativistic velocity (p/E) may be slowly convergent

since the value of $\langle p/E \rangle$ is usually pretty close to 1. Thus it seems more appropriate to consider the whole relativistic operator Eq. (2) in spite of the fact that it is to be sandwiched between $3q$ baryon wave functions obtained with a non-relativistic quark model. To this respect we assume that once fitted the spectroscopy, the non-relativistic $3q$ wave function may emulate the relativistic one when relativistic normalization and kinematical factors are considered [13].

The baryonic matrix elements for a process $B \longrightarrow B'\gamma$ are easily computed from the single-quark matrix element Eq. (1)

$$\begin{aligned} \langle B'\gamma(\vec{q}, \lambda)|H|B \rangle &= \frac{3}{(2\pi)^{3/2}} \frac{1}{(2\omega)^{1/2}} \delta^{(3)}(\vec{P} - \vec{P}' - \vec{q}) \\ &\int d\vec{p}_{\xi_1} \int d\vec{p}_{\xi_2} \Psi_{B'}^*(\vec{p}_{\xi_1}, \vec{p}_{\xi_2} + \sqrt{\frac{2}{3}}\vec{q}) \\ &\mathcal{O}_{qq\gamma}(\vec{p}_3, \vec{p}_3', \lambda) \Psi_B(\vec{p}_{\xi_1}, \vec{p}_{\xi_2}) , \end{aligned} \quad (3)$$

where \vec{P} (\vec{P}') is the three-momentum of the initial (final) baryon and \vec{p}_{ξ_1} and \vec{p}_{ξ_2} are the conjugate momenta of the Jacobi coordinates $\vec{\xi}_1$ and $\vec{\xi}_2$. Ψ stands for the wave function of the baryons and the single-quark transition operator has been particularized for the quark 3.

All the dependence on a specific quark model for the baryons is contained in the baryon wave functions. Hereforth we shall make use of a spectroscopic potential model, very much detailed elsewhere [12], which contains, aside from a linear confinement, the 'minimal' one gluon exchange-like terms. The explicit expression for the quark-quark potential is

$$V_I = \sum_{i < j} \frac{1}{2} \left[\frac{r_{ij}}{a^2} - \frac{\kappa}{r_{ij}} + \frac{\kappa}{m_i m_j} \frac{\exp(-r_{ij}/r_0)}{r_0^2 r_{ij}} \vec{\sigma}_i \vec{\sigma}_j - D \right] , \quad (4)$$

with $a^2 = 1.063 \text{ GeV}^{-1} \text{ fm}$, $\kappa = 0.52$, $r_0 = 0.4545 \text{ fm}$ and the quark mass is set to $m = 0.337 \text{ GeV}$. This potential provides very good results for the spectroscopy of low-lying baryons (ground states) as well as mesons. Concerning the excited states the energies are reasonably predicted with the exception of the Roper resonances.

To evaluate the electromagnetic form factor we have to consider the elastic eN scattering process. We take the Breit frame where $\omega = 0$, $\vec{q}^2 = Q^2$. We shall calculate the $N \rightarrow N\gamma$ amplitude from (3) and extract the form factors from the corresponding expression at the nucleonic level that reads:

$$\langle N\gamma(\vec{q}, \lambda)|H_{NN\gamma}|N \rangle = \frac{3e}{(2\pi)^{3/2}} \frac{1}{(2\omega_\gamma)^{1/2}} \delta^{(3)}(\vec{P}_B - \vec{P}_{B'} - \vec{q})$$

$$\chi'_N \left[\frac{G_E(Q^2)}{\sqrt{1 + \frac{Q^2}{4M^2}}} \epsilon_{\lambda}^{0*}(\vec{q}) - i \frac{G_M(Q^2)}{2M\sqrt{1 + \frac{Q^2}{4M^2}}} (\vec{q} \times \vec{\sigma}_N) \cdot \vec{\epsilon}_{\lambda}^*(\vec{q}) \right] \chi_N, \quad (5)$$

where $\vec{\sigma}_N$ is the spin operator acting on the nucleon spinors $\chi_N, \chi_{N'}$.

Results for the electric and magnetic form factors are shown in Fig. 2 (dashed lines) as compared to the conventional first-order (p/m) expansion (dash-dotted line) and to data. A look at the figures shows significant discrepancies between the two calculations even for low Q^2 values.

Regarding the electric form factor the slope of $G_E(Q^2)$ at the origin $Q^2 \rightarrow 0$, is related to the square mean charge radius of the nucleon. The (p/m)-expansion neglects contributions to the radius coming from higher orders. These contributions (Darwin-Foldy term) are present when the whole operator is used giving rise to a bigger charge radius as compared to the (p/m) value. Nonetheless in both cases it is still too small (0.238 fm² and 0.327 fm²) as compared to data ($\langle r_p^2 \rangle_{\text{Exp.}} = 0.74 \pm 0.02$ fm² [15]). This is a direct consequence of the reduced size of the nucleon wave function which seems to be an inevitable feature of any $3q$ model able to reasonably fit the spectrum.

Concerning the magnetic form factor, the magnetic moments calculated with (2) are a 30 % smaller than the ones obtained with the (p/m) expansion. The reason for this reduction is the presence, for $Q^2 = 0$, of the energy factor $1/(2E_3)$ in the vector part of the quark current instead of the mass factor $1/(2m)$. On the other hand the Q^2 dependence of this factor makes the magnetic form factor go faster to zero when increasing Q^2 as compared to the (p/m) case.

It is then clear the insufficiency of the EEM mechanism when combined with a spectroscopic quark model to explain the data, even if some relativistic kinematic corrections are included as in Eq. (2).

3 Dynamical relativistic corrections

Leaving aside for the moment kinematical corrections, we pay attention to dynamical relativistic corrections associated to the presence of quark-antiquark pairs in the baryonic medium. We certainly expect these corrections, that to some extent represent the effects of the mesonic cloud of the nucleon, to give sizeable contributions to the radius and to the magnetic moments as suggested by other approaches such as the relativistic chiral bag model.

Following the ideas developed in a previous paper [9] to treat strong pionic decays of baryons, we shall use the 3P_0 quark pair creation as a way to generate the extra $q\bar{q}$ pair in the baryonic medium. The 3P_0 operator written in a relativistic form reads:

$$\begin{aligned}
H_{3P_0} = & \beta \int d\vec{p} \left(\frac{m}{E_p} \right) \sum_{s,\tau,s',\tau'} \left\{ \bar{u}_{s,\tau}(\vec{p}) v_{s',\tau'}(-\vec{p}) b_{s,\tau}(\vec{p}) d_{s',\tau'}^\dagger(-\vec{p}) \right. \\
& \left. + \bar{v}_{s,\tau}(\vec{p}) u_{s',\tau'}(-\vec{p}) d_{s,\tau}(\vec{p}) b_{s',\tau'}^\dagger(-\vec{p}) \right\} , \quad (6)
\end{aligned}$$

where u, v stand for Dirac four-spinors and b, d are the usual annihilation quark and antiquark operators. β is an effective strength parameter that controls the pair formation in the hadronic medium. From Eq. (6) it is easy to check by keeping terms up to (\vec{p}/m) order that one can recover the conventional non-relativistic 3P_0 Hamiltonian [14].

In this scenario, two contributions can be considered. First the recombined quark-antiquark pair propagates in a resonant state which must be a vector meson in order to have the photon quantum numbers (Fig. 1b). At low momentum transfer ($Q^2 \lesssim 2\text{-}3 \text{ GeV}^2$) we can restrict ourselves to the ρ and ω mesons. On the other hand, there is no reason to think that this resonant contribution saturates the $|qqq q\bar{q}\rangle$ component and there could be non-resonant propagation of the quark-antiquark pair as well (Fig. 1c).

1. Resonant Diagrams. The resonant amplitude is written from Fig. 1b. by considering the two possible time orderings corresponding respectively to the vector meson propagating forward and backward in time.

For the electromagnetic vector meson-photon vertex we assume a self-gauge invariant coupling $f_V F^{\mu\nu} V_{\mu\nu}$ that guarantees that each time-ordered diagram is gauge invariant separately.

For the strong quark-antiquark vector meson vertex $\langle q|H_{3P_0}|qV\rangle$ we use the previously defined 3P_0 model, where the vector meson state is written in its relativistic form:

$$\begin{aligned}
|V(\vec{q}_V, \epsilon_V)\rangle = & -\frac{1}{2} \sum_{s,\tau,s',\tau'} \int d^3p_q d^3p_{\bar{q}} \Phi\left(\frac{\vec{p}_q - \vec{p}_{\bar{q}}}{2}\right) \delta(\vec{p}_q + \vec{p}_{\bar{q}} - \vec{q}_V) \\
& \bar{u}_{s,\tau}(\vec{p}_q) \gamma_\mu \mathcal{O}_\tau v_{s',\tau'}(\vec{p}_{\bar{q}}) \epsilon_V^\mu(\vec{q}_V) b_{s,\tau}^\dagger(\vec{p}_q) d_{s',\tau'}^\dagger(\vec{p}_{\bar{q}}) |0\rangle , \quad (7)
\end{aligned}$$

where \mathcal{O}_τ fixes the isospin wave function of the meson state ($\mathcal{O}_\tau = \vec{\tau}(1)$ for an isovector (isoscalar) meson). For the internal wave function Φ we have taken a Gaussian form $\Phi(\vec{k}) = (R_V/\sqrt{\pi})^{3/2} \exp(-k^2 R_V^2/2)$ whose parameter R_V is fixed to the leptonic decay width of the ρ meson. Additional checks with a Coulombian wave function shows that results are little sensitive (less than 5 %) to the choice of the functional form of Φ . Moreover, in the following we will assume for the sake of simplicity the SU(3) relationship $f_\omega = 3f_\rho$ and take for the ρ and ω an averaged mass $m_V = (m_\rho + m_\omega)/2$. The resulting single-quark transition operator in the Breit frame ($\omega = 0$) is:

$$\begin{aligned}
O_{q\bar{q}\gamma}^V(\vec{p}, \vec{p}', \lambda) &= -e_q \frac{\beta}{f_V} \frac{E_V^{1/2}}{(2)^{3/2}} \Phi_V^* \left(\frac{1}{2}(\vec{p} + \vec{p}') \right) \frac{1}{Q^2 + m_V^2} \\
&\times \left\{ \epsilon_\lambda^{0*}(\vec{q}) \left(E_V - \frac{Q^2}{E_p + E_{p'}} \right) \left(\frac{\vec{\sigma} \cdot \vec{q} \vec{\sigma} \cdot \vec{p}}{E_p} - \frac{\vec{\sigma} \cdot \vec{p}' \vec{\sigma} \cdot \vec{q}}{E_{p'}} \right) \right. \\
&- \left. \vec{\epsilon}_\lambda^*(\vec{q}) \cdot \left[\frac{\vec{\sigma} \cdot \vec{p}'}{E_{p'}} (Q^2 \vec{\sigma} - (\vec{\sigma} \cdot \vec{q}) \vec{q}) + (Q^2 \vec{\sigma} - (\vec{\sigma} \cdot \vec{q}) \vec{q}) \frac{\vec{\sigma} \cdot \vec{p}}{E_p} \right] \right\}. \tag{8}
\end{aligned}$$

2. Non-resonant diagrams. By proceeding in the same manner one can evaluate the matrix element of the single-quark transition operator for the non-resonant propagation of the quark-antiquark pair. However, a difficulty immediately arises since this operator, by its own, does not give rise to a conserved current. In order to see how gauge invariance can be recovered it is necessary to understand the underlying physics in the 3P_0 operator.

4 Gauge invariant current

Let us assume that the 3P_0 operator is generated by some residual interaction between quarks and gluons inside the baryon. This residual interaction may be very complex and its detailed description would tantamount to unveil the structure of the hadronic vacuum. Nonetheless, we shall show in a simplified model that the generation of the pair from the vacuum (i.e. the use of the 3P_0 operator) must be accompanied by a mass renormalization. This mass renormalization directly connected to the strength β allows one to restore gauge invariance.

The simplest modelization one can do of the residual interaction is through the coupling of the quarks to a scalar mean field $B(x)$:

$$\mathcal{L} = -g\bar{q}(x)B(x)q(x) \ , \tag{9}$$

where g is some unknown coupling constant. Four types of diagrams come from Eq. (9). Two of them correspond to the 3P_0 $q\bar{q}$ creation and annihilation under the identification $\beta = gB(x)$. The other two diagrams give rise to a mass renormalization for quark and antiquark which can be written as $m = m_0 + gB(0)$. In general the renormalized mass m may be a very complicated function of m_0 and g , but since we are interested in transition operators up to order β , it can be reduced to the linear relationship quoted above. The important fact is that the use of the 3P_0 model leads consistently to a mass renormalization.

Now we are in conditions to understand how gauge invariance can be recovered. The renormalization of the mass breaks the conservation of the current associated to the EEM. Indeed, the mass that appears in Eq. (2) has to be interpreted as a bare mass m_0 and as a consequence the current associated to the EEM is not conserved anymore. The breaking term is of the order $(E_p - E_{0p})$, where $E_{0p} = \sqrt{m_0^2 + \vec{p}^2}$ is the energy corresponding to the unrenormalized mass. However, the operators have to be written eventually in terms of the physical mass m and therefore one has to replace m_0 by their value in terms of the physical mass. When doing so, the terms that break gauge invariance in the EEM current and in the non-resonant sector cancel each other under the requirement:

$$m = m_0 + \beta/2 . \quad (10)$$

The resulting final single-quark transition operator, which respects gauge invariance, is written as a sum of three terms:

$$O_{qq\gamma}(\vec{p}, \vec{p}', \lambda) = O_{qq\gamma}^{\text{EEM}}(\vec{p}, \vec{p}', \lambda) + O_{qq\gamma}^{\text{V}}(\vec{p}, \vec{p}', \lambda) + O_{qq\gamma}^{\text{NR-EEM}}(\vec{p}, \vec{p}', \lambda) , \quad (11)$$

where $O_{qq\gamma}^{\text{EEM}}$ and $O_{qq\gamma}^{\text{V}}$ are given by Eqs. (2) and (8) respectively being m the physical mass and

$$\begin{aligned} O_{qq\gamma}^{\text{NR-EEM}}(\vec{p}, \vec{p}', \lambda) &= e_q \frac{\beta}{8\sqrt{E_p E_{p'}(E_p + m)(E_{p'} + m)}} \vec{\epsilon}_\lambda^*(\vec{q}) \\ &\times \left[i(\vec{\sigma} \times \vec{p}') \left(\frac{\vec{p}^2}{E_p^2} + \frac{\vec{p} \cdot \vec{p}'}{E_{p'}^2} \right) - i(\vec{\sigma} \times \vec{p}) \left(\frac{\vec{p}'^2}{E_{p'}^2} + \frac{\vec{p} \cdot \vec{p}'}{E_p^2} \right) \right. \\ &\left. - i\vec{\sigma} \cdot (\vec{p}' \times \vec{p}) \left(\frac{\vec{p}}{E_p^2} + \frac{\vec{p}'}{E_{p'}^2} \right) + i(\vec{p} \times \vec{p}') \left(\frac{\vec{\sigma} \cdot \vec{p}'}{E_{p'}^2} + \frac{\vec{\sigma} \cdot \vec{p}}{E_p^2} \right) \right] . \end{aligned} \quad (12)$$

5 Results and discussion

The nucleon form factors obtained from our final gauge invariant operator are shown in Fig. 2 (solid lines). The value of the only free parameter β has been chosen so that the magnetic moment of the proton is fitted to its experimental value. The neutron magnetic moment is also well reproduced, $\mu_n = -1.89$.

As a general result we can say that in all cases the model represents an important improvement with respect to the EEM predictions (dashed lines). A comparison between the two sets of curves gives a quantitative idea of the

contribution of the $|qqq\ q\bar{q}\rangle$ components to the electromagnetic structure of the nucleon.

The magnetic form factors are precisely reproduced up to $Q^2 = 1.2\text{ GeV}^2$ (notice the Q^4 in the scale). The main (positive) contributions comes from the EEM, which gives up to 60 % at $Q^2 = 0$ (see Fig. 3). The non-resonant contribution (NR-EEM) is also positive and it is very relevant at low Q^2 . In particular it gives almost a 40 % of the magnetic moment of the proton μ_p . Finally, the resonant operator contribution is negative and vanishes at $Q^2 = 0$, i.e. it gives no contribution to the magnetic moments. As expected on general grounds, the contribution of these mesonic components is important only around the mass pole, though its absolute value in this model is still small as compared to the non-resonant propagation.

Concerning the electric form factor, results differ from data and follow the same trend in the whole range of Q^2 examined. The predicted charge square mean radii ($\langle r_p^2 \rangle = 0.48\text{ fm}^2$ and $\langle r_n^2 \rangle = -0.06\text{ fm}^2$) are still small as compared to data ($\langle r_p^2 \rangle = 0.74 \pm 0.02\text{ fm}^2$ [15] and $\langle r_n^2 \rangle = -0.1215 \pm 0.0016\text{ fm}^2$ [17]). It is remarkable that the resonant diagram accounts for 30 % of $\langle r_p^2 \rangle$ whereas the EEM diagram, that includes Darwin-Foldy terms and other higher corrections gives 0.32 fm^2 . The lack of some contributions to the square mean radius is manifest through the slope of the curves at Q^2 which determines the difference with data at higher Q^2 . As can be seen from Eq. (12), the non-resonant term does not take part in the electric transitions since their time-like component vanishes. Regarding the small value of the neutron charge radius, it should be realized that in our case we have used SU(6) relations ($m_\rho = m_\omega$, $f_\omega = 3f_\rho$) so that the diagonal contributions of the SU(6) symmetric component of the wave function (98.5 %) vanishes. The breaking of the former relations (coupling to 2π in one case, to 3π in the other for instance) could significantly change the charge radius of the neutron with very small effects on the other form factors.

The effective constant β parametrizes, in the simplest way, the creation of $q\bar{q}$ pairs in the hadronic medium. Its effectiveness reflects gluon exchange interactions, maybe mostly related to the confinement potential and other non-perturbative effects. With respect to its particular value, and to ensure the consistency of the whole scheme, strong processes such as pionic decays of resonances, and photo and electroproduction of resonances should be described within the same model and with the same value of β [18]. Therefore not much can be said about the reasonable value of β until this medium term program is carried out.

Our results can be compared with those of Ref. [19], where exchange currents and quark form factors contributions to the charge radii are evaluated. The effects of exchange currents are partially taken into account in the 3P_0 model through the effective value of β . However, ρ and ω propagation diagrams in our model incorporate quark-antiquark interactions and would thus

be related to quark form factors rather than to exchange currents.

Finally, some comments are in order about the kinematical relativistic corrections, which have been also the subject of recent interest [7]. Undoubtedly these corrections are important and affect the predicted values of the form factors by introducing new Q^2 dependences which can also contribute to the square charge radius. For example, the authors of Ref.[7] obtain a value for $\langle r_n^2 \rangle$ close to the experimental number. Nonetheless we do not think that they could play, in an effective way, the role of the dynamical mechanisms described here: in particular concerning the contributions of the ρ and ω mesons to the nucleon form factors. As a matter of fact one could use a simple counting of the normalization and boost factors when employing relativistic wave functions instead of non-relativistic ones [13] without invoking the detailed dynamics at all.

In summary we have developed a consistent model to treat some relativistic dynamical corrections to the nucleon form factors. The model operator includes the effect of $|qqq\ q\bar{q}\rangle$ baryon components generated through a 3P_0 mechanism. Gauge invariance is ensured through the mass renormalization associated to such a mechanism. The only free parameter in the model is β , the strength of the creation of pairs in the hadronic medium, which is fitted to the magnetic moment of the proton. The results obtained seem to confirm our initial expectations about the consideration of $q\bar{q}$ contributions as an essential physical ingredient in the description of electromagnetic transition processes.

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Figure captions

Figure 1 (a) Elementary emission model: the photon is emitted by one of the constituent quarks. (b) Resonant propagation of a $q\bar{q}$ pair relevant for electromagnetic interactions. (c) Non-resonant propagation of a $q\bar{q}$ pair. In (b,c) the creation of the extra $q\bar{q}$ pair is described by the 3P_0 model (crosses).

Figure 2 Nucleon electromagnetic form factors calculated with the operator (11) (solid line). Dashed lines show the contribution of the EEM, Eq. (2) and dash-dotted lines correspond to the case where only the lowest order in (p/m) is retained in Eq. (2). For experimental data see [16].

Figure 3 Relative contributions of the terms in Eq. (11) to the total value of G_M^p/μ_p (solid line). The short-dashed line corresponds to the EEM term, the long-dashed line to the V term and the dash-dotted line to the NR-EEM contribution.

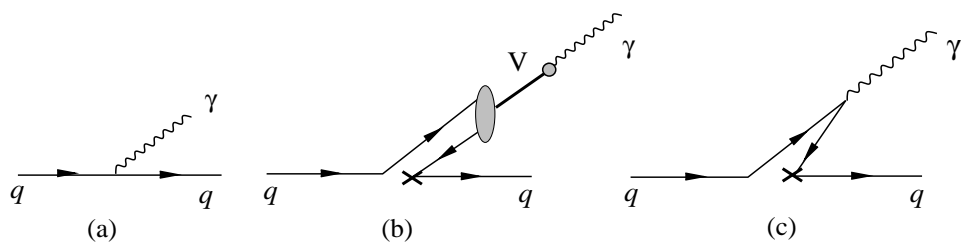


Figure 1.

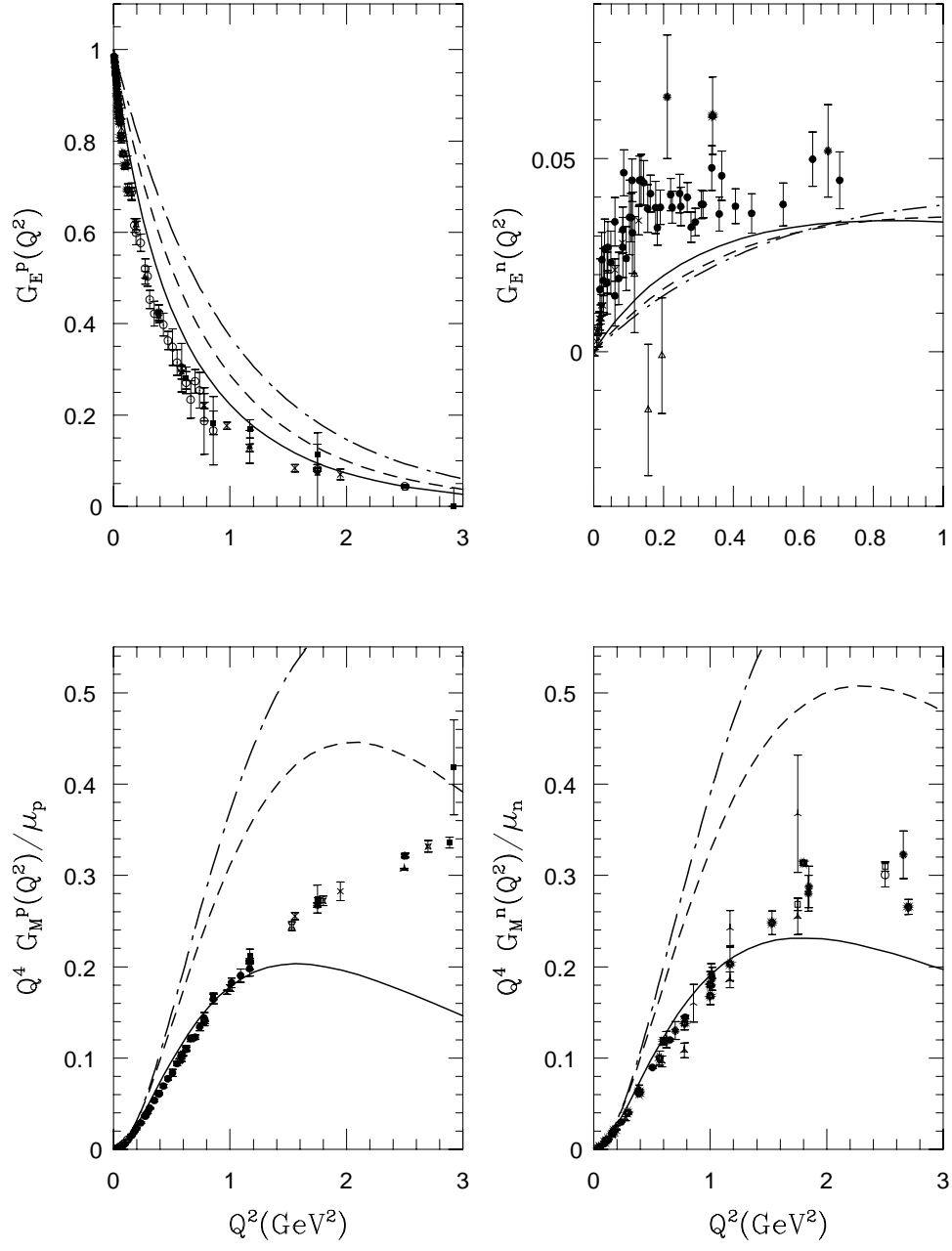


Figure 2.

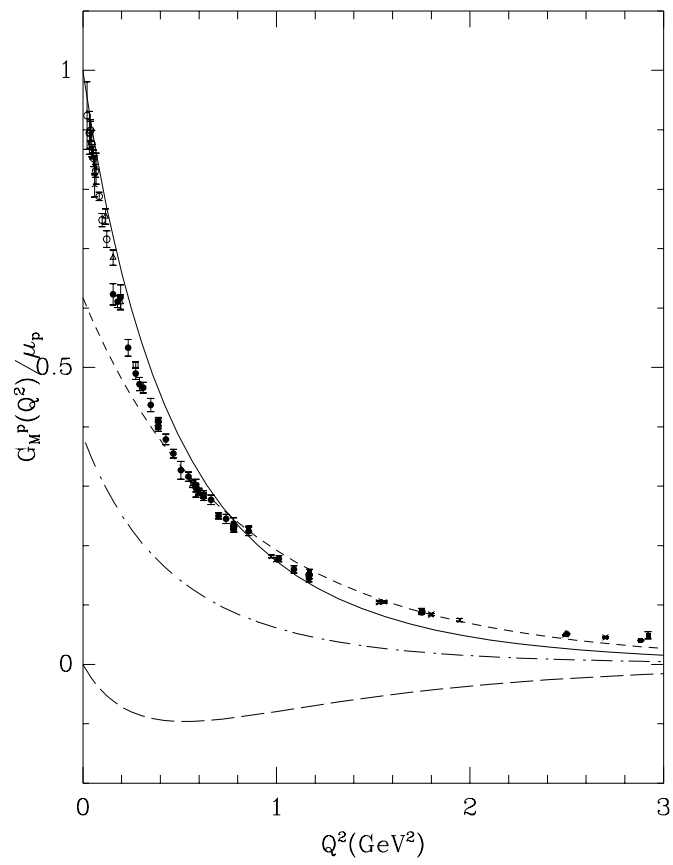


Figure 3.